# SIRIO: ONE YEAR OF STATION KEEPING

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## ABSTRACT

About one year ago SIRIO was successfully launched and guided to its geostationary target position by a joint team composed of NASA and Italian technicians. The strategy followed in maintaining the station point and the results achieved are here briefly described.

The method used at the Fucino control center for orbit determination is presented. Azimuth and elevation data from SHF antennas located at Fucino and Lario are used as input for the determination. An estimation of the uncertainty of the orbit is given; a comparison is made between determinations performed using the method here described and determinations performed using VHF ranging data. Also, the difference in using data from a single SHF station or two stations is shown.

In the area of attitude determination, a study has been carried out for predicting the spacecraft spin axis precession. The model used is explained and then the agreement between predicted and measured attitude outlined.

# One year of station keeping

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## Introduction

The SIRIO project is an important research program sponsored by the Consiglio Nazionale delle Recerche (CNR), the Italian National Research Council, to perform telecommunication experiments on Super High Frequency (SHF) bands (12-18 GHZ) over a two year period.

While the SIRIO satellite was designed and assembled in Italy, CNR contracted with the U.S. National Aeronautics and Space Administration (NASA) to provide the launch vehicle (a 2313 Delta rocket) and the necessary ground assistance to launch and position the satellite in orbit.

SIRIO was launched from Cape Canvaral on August 25, 1977 at 23.50 hours GMT. After spacecraft separation, control was taken over by the MultiSatellite Operation Control Center (MSOCC) at the Goddard Space Flight Center (GSFC) and a joint team of NASA and Italian technicians operated to bring the satellite to the desired station point. After completion of station acquisition maneuvers, the control of the satellite was handed over to Sirio Italian Operation Control Center (SIOCC) located at Fucino, near Rome. This paper briefly describes the experiences gained while maintaining the SIRIO station point during its first year of operational life.

Since SIRIO is Italy's first geostationary spacecraft in orbit, the necessary familiarity with flight control procedures was mainly acquired by the Italian team during the period of cooperation with the NASA. In fact, no relevant new techniques have since been adopted, which differ from those used by the NASA to control geostationary satellites. Consequently, this paper is limited to providing an evaluation of the precision reached in determining the orbit and attitude of the spacecraft and in approaching the target when executing maneuvers, without going into detail concerning the particular techniques used.

There is one exception to this rule: the orbit determination. A description is given of how satisfactory results were achieved using the Fucino SHF antenna pointing data instead of following the procedure based on Very High Frequency (VHF) ranging data, which was used by NASA during the first period of the mission.

## Mission Objective

In order to point the on-board SHF antenna on the area of the Baleari Isles in the Mediterranean (optimal sub-antenna point for the SHF experiments), the spacecraft had to be positioned on an equatorial plane with a tolerance of .3 degrees in orbit inclination at a longitude of 15 degrees ± 1 degree W; furthermore the spin axis declination had to be maintained within 1 degree of the negative orbit normal, and, since the satellite is spin stabilized, the spin rate had to be maintained at 90 ± 1 rounds per minute. It was necessary that 12 kg of hydrazine remained at hand-over in order to insure the two year period of operational life.

## Hand Over to SIOCC (SIRIO Italian Operation Control Center)

The SIRIO mission evolved in continuously nominal conditions. The final trim maneuver was performed on September 15 with the following results:

- spacecraft longitude = 14.61 degrees
- orbit inclination = .311 degrees
- spin axis declination = - 89.64 degrees
- spin rate = 90.5 rounds per minute
- 24 kg hydrazine left

After testing the spacecraft health status and the complete readiness of the SIOCC for operations, handover was operative on September 29 at 24.00 GMT. At that point the orbit inclination had lowered to below .3 degrees and thus everything was nominal.

GSFC continued orbit determination support via VHF ranging measurements on a biweekly basis until the end of 1977. In parallel, Telespazio began the determinations based on the SHF ground antenna pointing data which, from the beginning of 1978, have been carried on stand alone.

## Station Keeping Operative Limits

After handover, it was found convenient to reduce the tolerances of the mission in order to avoid time constraints in performing maneuvers and to insure a more accurate antenna pointing. The actual operative constraints for SIRIO are the following:

- spacecraft longitude = 15 degrees W ± .5 degrees
- orbit inclination = .2 degrees
- spin axis declination = - 89.80 degrees
- spin rate = 90 ± 1 round per minute

With the new constraints, the average period between cycles of maneuvers is about 5 months. Maneuvers are normally planned to occur in a series of two or three different corrections closely linked in time to each other (North-South, East-West and attitude corrections). Since the tolerances are not critical, in order to phase the maneuvers, the spacecraft can be left drifting out of the imposed limits for a short time.

## Mission Control Ground Equipment

SIOCC is equipped with a front-end computer utilized for spacecraft telemetry control, spacecraft command, for performing the first level of computations on experimental data, for archiving, etc.. The flight dynamics control tasks are performed by the CNUCE computing systems at Pisa, connected to the SIOCC, via data link, for telemetry data transmission. A joint team from Telespazio and CNUCE is encharged with the spacecraft control planning; Telespazio is responsible for the operations on the spacecraft while CNR is responsible for the mission as a whole.

## Orbit History

In fig. 1, the longitude of the spacecraft subsatellite point is shown over a one year period together with the inclinations of the orbital plane. The curve discontinuities clearly show the occurrence of the orbital maneuvers while the attitude corrections have been so small that no practical influence on the orbit can be seen.

## Attitude History

Fig. 2 shows the attitude history in a polar diagram; the two attitude corrections and the perturbation caused by the North-South maneuver of May 2 are clearly shown. The diagram can be used to predict attitude in the second year of spacecraft life and to tune the mathematical models at present under study which aim at representing the spin axis precession movement in a trial and error procedure.

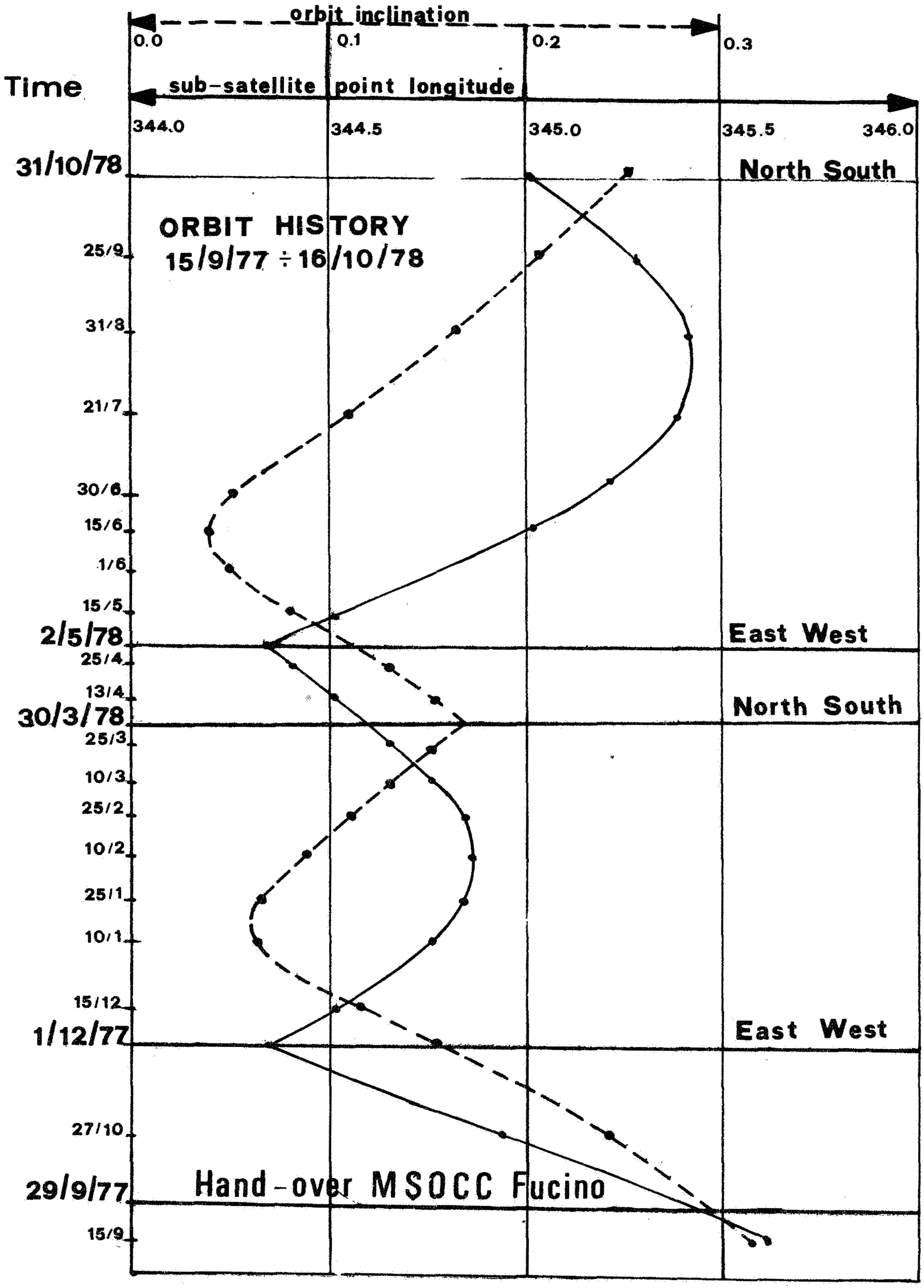
orbit inclination
0.0
0.1
0.2
0.3
Time
sub-satellite point longitude
344.0
344.5
345.0
345.5
346.0
31/10/78
North South
ORBIT HISTORY
15/9/77 ÷ 16/10/78
25/9
31/8
21/7
30/6
15/6
1/6
15/5
2/5/78
East West
25/4
13/4
30/3/78
North South
25/3
10/3
25/2
10/2
25/1
10/1
15/12
1/12/77
East West
27/10
29/9/77
Hand-over MSOCC Fucino
15/9

Figure 1

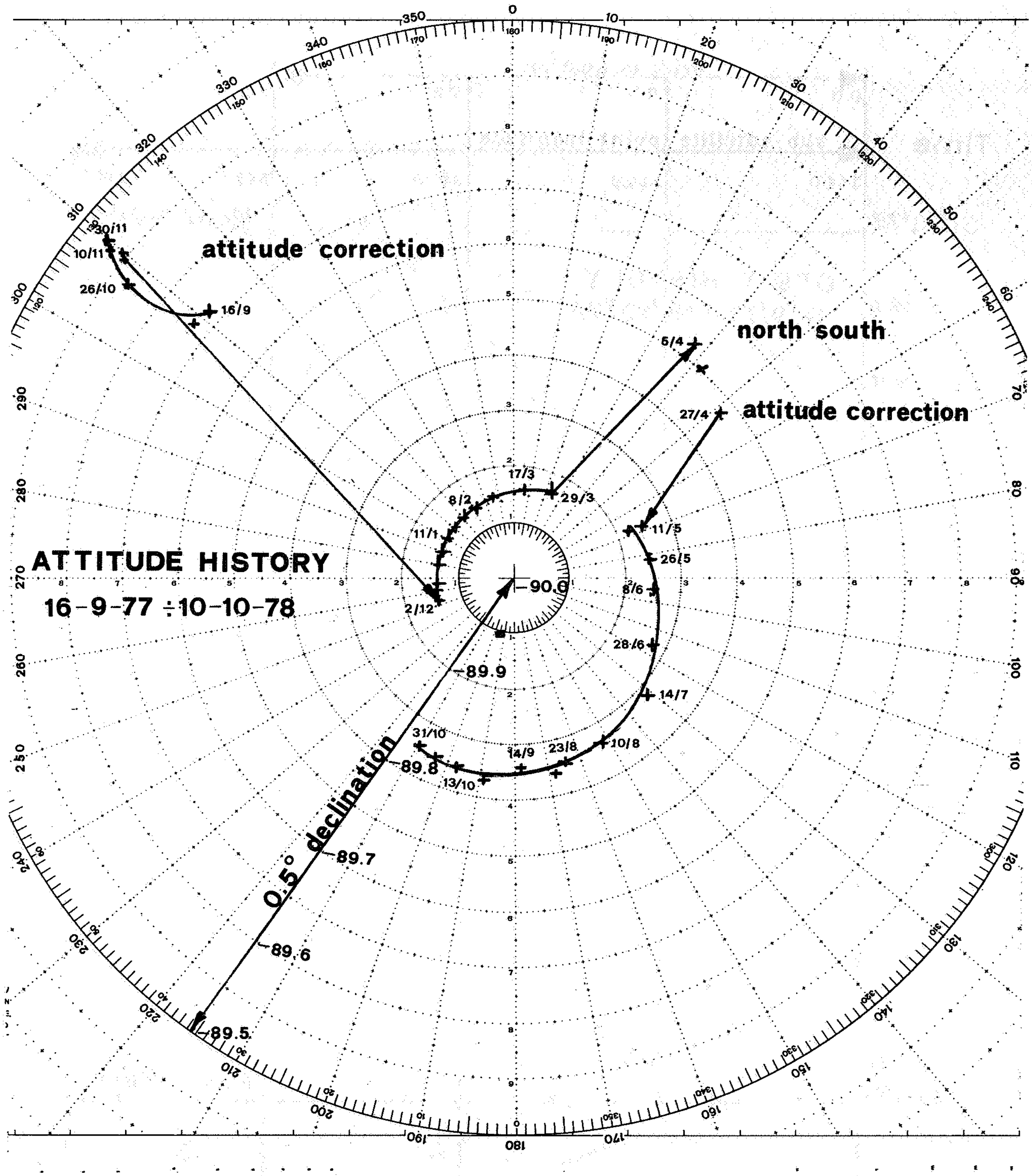
attitude correction
north south
attitude correction
ATTITUDE HISTORY
16-9-77 ÷10-10-78
0.5° declination
30/11
10/11
26/10
16/9
5/4
27/4
17/3
29/3
8/2
11/1
2/12
11/5
26/5
8/6
28/6
14/7
10/8
23/8
14/9
13/10
31/10
-90.0
-89.9
-89.8
-89.7
-89.6
-89.5

Figure 2

## Maneuvers

In the table included with fig. 3, an outline of the maneuvers performed on the SIRIO satellite is given. In consideration of the fact that the granularity, which can be reached by the satellite auxiliary propulsion system when firing a single pulse is relatively large, the results were always very satisfactory.

| DATE | TYPE | JETS | PULSES OR BURNTIME | TARGET | RESULTS |
|---|---|---|---|---|---|
| DEC 1 77 | E-W | RAD B | 12 PULS | 15.° LONG ON 03/26/78 | 15.4°LONG on 03/26/78 |
| DEC 1 77 | ATT | AX B | 4 PULS | RA = 218° DEC=-89.88° | RA = 255° DEC=-89.93° |
| MAR 30 78 | N-S | AX A+B | 110 SEC | INCLIN=.18° NODE=270° | INCLIN=.168° NODE=272.2° |
| MAY 2 78 | E-W | RAD B | 11 PULS | INITIAL DRIFT .0125deg dayW FINAL DRIFT .0210deg dayE | FINAL DRIFT .0202deg dayE |
| MAY 2 78 | ATT | AX B | 2 PULS | RA=53° DEC=-89.93° | RA=66.50° DEC=-89.88° |

Figure 3

## Mission situation at Midway point

At midway point in its operational life, SIRIO continues regular transmission of experimental data; no major or chronic failures have occurred either on the SIRIO payload or in the basic spacecraft. All those elements subject to degradation, e.g. batteries, solar pannels, etc., have had a lower degradation rate than expected.

The hydrazine tanks still contain approximately 20.5 kg of fuel; after the North-South maneuver, which is programmed for October 31, we expect to have approximately 18.5 kg left.

As the average yearly fuel consumption necessary to maintain the present station point is approximately 4 kg, we should have enough fuel left to considerably extend the spacecraft life. No final decision has so far been taken but there are already plans for utilizing SIRIO for a number of additional experiments.

## Attitude Determination

In the present geostationary position, 250 major frames are selected from a 24 hour period of data for each determination.A least square filter is used to determine the:

- spin axis right ascension
- spin axis declination
- sun angle bias
- sun sensor mounting angle bias
- sun to earth in bias

All the biases are presumed to be constant over the 24 hour period. Earth radius bias cannot be determined in the present satellite position but it has already been determined during the GSFC controlled mission phase.

Two verifications are applicable to validate the solution of the attitude given by the filter. In the first, biases are inserted in two deterministic methods to resolve the attitude frame by frame; this first method resolves the attitude by using sun-angle and sun-to-earth-in data, the second one by using sun-angle and earth-length data. A graphic display then provides the dispersions of these resolved attitudes from the one computed by the filter; the trend of the resolved attitudes over the time span covered by the selected frames gives also an indication of the correctness of the determined biases.

A second verification is made using the attitudes and the biases determined by the filter in order to simulate telemetry data. A graphic comparison between simulated and acquired telemetry data confirms this solution. At the end of this process, the attitude of the satellite is determined in geostationary position with a 3 sigma coning angle of .1 degree.

## Orbit Determinations

The Sirio orbit determination method is based on angular observations, supplied by the Fucino SHF telecomunications antenna.

The azimuth and elevation angles are automatically acquired at intervals of one hour. An orbit determination process is statistically significant with a number of observations from 200 to 500, made over a time period from 5 to 10 days. A smaller number of observations makes the estimation process more critical or even impossible, while the use of data from a period of more than 10 days does not really improves the orbit estimation accuracy.

The observations are supplied by the SHF telecommunications antenna, which is a 17 m. paraboloid, working in the 12 and 18 GHZ bands; the beam width at 3 db is

.045 deg, and the digital encoders accuracy is .01 deg. The nominal tracking error, in autotracking mode, is .01 deg (3sigma), and the nominal pointing error (bias) is .01 deg (1sigma) both in azimuth and in elevation.

The mathematical model used in the estimation process takes into account the 5x5 geopotential, and the perturbations due to the sun and the moon; the Cowell numerical integrator is used, with an integration step of 800 sec. The estimation process is based on a differential correction method.

The spacecraft position accuracy (x,y,z) varies from 200 to 500 m (1sigma), and the velocity accuracy ($\dot{x},\dot{y},\dot{z}$) is in the order of 3 cm/sec (1sigma); this corresponds to a longitude uncertainty of 2x10 deg (1sigma) at determination epoch.

The accuracy of the statistical process is quite good, due to the very high quality of angular data supplied by the SHF antenna. The real limitation of the method is caused by the observation biases. A periodic check of the pointing accuracy of the antenna can not be made, for operational reasons; the observation bias, measured before the beginning of the mission, was within the nominal limits (.01deg.), and the a priori value is assumed to be zero.

The orbit accuracy has been tested by an independent source, the NASA determinations performed from September to December 1977. The agreement between the NASA and TELESPAZIO determinations is quite satisfactory; as can be seen from the table of fig 4, the differences in semimajor axis, eccentricity and inclination are very low. The node and perigee arguments and mean anomaly are less accurate; this is due to the very low inclination of the geostationary orbit. Very important, however, is good agreement in the spacecraft right ascension, which is roughly the sum of $\Omega$, $\omega$, M.

| EPOCH: 1977 | SEPT. 15, 18.00 | | OCT. 27, 00.00 | | DEC. 2. 00.00 | |
|---|---|---|---|---|---|---|
| | NASA | TELESPAZIO | NASA | TELESPAZIO | NASA | TELESPAZIO |
| SEMIMAJOR AXIS (KM) | 42165.530 | 42165.458 | 42168.584 | 42168.216 | 42164.359 | 42164.117 |
| ECCENTRICITY | $0.348\ 10^{-3}$ | $0.321\ 10^{-3}$ | $0.261\ 10^{-3}$ | $0.259\ 10^{-3}$ | $0.215\ 10^{-3}$ | $0.202\ 10^{-3}$ |
| INCLINATION (DEG) | 0.306 | 0.309 | 0.235 | 0.244 | 0.161 | 0.154 |
| ASCENDING NODE (DEG) | 250.728 | 251.140 | 250.752 | 249.371 | 249.363 | 247.986 |
| ARGUM. OF PERIGEE (DEG) | 239.119 | 239.957 | 237.562 | 239.334 | 234.912 | 239.754 |
| MEAN ANOMALY (DEG) | 120.112 | 118.683 | 251.875 | 251.496 | 290.806 | 287.356 |
| SUM OF $\Omega$, $\omega$, M (DEG) | 249.959 | 249.980 | 20.189 | 20.201 | 55.081 | 55.096 |

Figure 4

Another independent source of information, which has been used to verify the Sirio orbit determination method, is the optical observation. This is possible twice per year, when the sun declination is equal to the spacecraft declination in an hour angle declination reference system centered at the observer. In this situation the sun light is reflected to the observer by the spacecraft which has his spin axis normal to the equatorial plane. Two optical observations were performed in March and October 1978, using amateur high quality equipment, with an observation error in the order of .003 deg.

The Sirio position has been measured on photographic plates with respect to a star with a known position. The March observation gave a difference between the nominal and the observed positions of .018 deg both in rigth ascension and declination; the October observation gave a difference of .022 deg in rigth ascension and .005 deg in declination. Therefore, main features of the Sirio orbit dtermination method are the following:

- simplicity : the observations acquisition is automatic, with no intervention of the operator, and without any interference with spacecraft operations;

- low cost : no additional equipment is required , other than that used for telecommunications;

- the accuracy is compatible with the requirements of the Sirio mission, in particular, and, in general, with those of the geostationary telecommunications missions;

-this method seems to be applicable for future telecommunications missions, with frequency bands in the 12-14 or 20-30 GHZ range.

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